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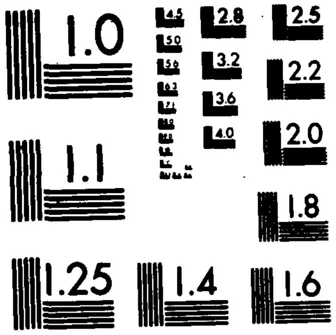

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DEPARTMENT OF DEFENCE

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MELBOURNE, VICTORIA

REPORT

MRL-R-1099

ANOMALOUS SHOCK SENSITIVITY/DENSITY RELATIONSHIP FOR RDX-POLYETHYLENE WAX AND RELATED FORMULATIONS FROM MRL SMALL SCALE GAP TEST (SSGT) MEASUREMENTS

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ABSTRACT

Shock sensitivity as measured by the MRL SSGT shows a consistent trend to lower values as %TMD decreases for pressed RDX formulations and some pure explosives such as tetryl. Decrease in particle size, disruption of surface coating, critical diameter and run distance effects were all considered but found not to be the major cause. Comparison of MRL SSGT data for a series of production booster explosives with corresponding NOL SSGT data at 90 %TMD suggested that the ability to undergo buildup is significantly more important for the MRL SSGT. Reasons for this difference are discussed, and limitations for assessment of data using the MRL SSGT are outlined.

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CONTENTS

ANOMALOUS SHOCK SENSITIVITY/DENSITY RELATIONSHIP FOR RDX-POLYETHYLENE WAX AND RELATED FORMULATIONS FROM MRL SMALL SCALE GAP TEST (SSGT) MEASUREMENTS

1. INTRODUCTION

The shock sensitivity of pressed granular explosives is routinely measured by gap tests [1-7]. In these tests the shock from a standard explosive charge (the donor) is attenuated through an inert mechanical barrier (the gap) and is then incident on the explosive under test (the acceptor). Success/fail is judged by formation of a dent in a witness plate, signifying detonation of the acceptor charge. The width of the gap is varied using a staircase go/no-go procedure [8] over a series of firings and the results are analysed statistically to yield a gap thickness at which there is a 50% probability of detonation ($m_{50\%}$), the usually cited figure. In several tests the relationship between gap thickness and incident shock pressure has been determined, and the latter parameter is then usually cited.

The most widely used gap tests are those developed at Naval Ordnance Laboratories (now Naval Surface Warfare Center); the small scale gap test (NOL SSGT) [2, 9] and large scale gap test (NOL LSGT) [2, 10]. A large body of data from these and the related Los Alamos gap tests [3] has been published [2, 3, 5, 9, 10]. At MRL we use a SSGT similar to the AWRE SSGT [6]. Full details have previously been published [11] and the experimental arrangement is shown in Fig. 1. The donor consists of an exploding bridge-wire (EBW) detonator, 5.57 mm i.d., filled with PETN, and the acceptor is two pressed cylindrical pellets each 12.7 mm diameter, 12.7 mm high.

Shock sensitivity, as determined by gap testing, shows a wide variance over the range of explosives that have been studied. For each type of explosive two material properties significantly affect shock sensitivity: grain size and packing density. The relationship between shock sensitivity and packing density (%TMD) is often presented as being straightforward. For example, Roth [1] states that "Without exception the shock sensitivity of any explosive increases as its (packing) density is decreased", while Price [12] states that "The trends in critical initiation pressure (P_g) versus %TMD are the same

for all porous explosives. The higher the %TMD, the higher P_g (hence smaller the gap in a gap test), which means the less sensitive the explosive. The more porous the explosive, the more sensitive it is". A number of exceptions have been observed, one key example being tetryl. Seely [13] noted a reversal in the SSGT shock sensitivity/density relationship for coarse tetryl over the density range 1.4-1.6 Mg/m^3. At lower and higher density, or for fine tetryl over the entire density range 1.1-1.7 Mg/m^3, the "normal" relationship described above was observed [13]. Dinegar and Millican also observed that higher density tetryl charges were more sensitive than lower density [14]. Composition A-3 (RDX/wax 91:9) has also been observed to increase in shock sensitivity with density over the range 85-96 %TMD using a wax gap test [15]. Other such reversals in behaviour can be found in the literature [2,3,5] but the tetryl and A-3 data represent the only examples not from our laboratories which cover an appreciable %TMD range.

One of us (WSW) reported in 1978 that the shock sensitivity of pressed RDX Grade B/polyethylene wax (92.3:7.7) and related formulations, as measured by the MRL SSGT, decreased with decreasing density over the range 96-89 %TMD [16]. This trend was also subsequently observed for pressed RDX Grade A/polyethylene wax (91.9:8.1) [17]. More recently we have observed these same trends for pressed RDX Grade A/polyethylene wax at lower wax levels [18] and also for pressed RDX Grade A/polyurethane/zinc stearate formulations [19]. These results are clearly in conflict with the consistent trends observed from other gap tests, particularly the NOL SSGT [2, 9]. The aim of the study described here was to identify the cause of this discrepancy.

2. RESULTS

MRL SSGT data for a series of pressed RDX Grade A/AC629 polyethylene wax are detailed in Table 1. In Table 2, corresponding data for RDX Grade B/AC629 (92.3:7.7), RDX Grade A/Impranil DLH polyurethane dispersion/zinc stearate (100.0:2.00:1.03), CH-6 (RDX/polyisobutylene/calcium stearate/graphite 97.5:0.5:1.5:0.5) and crystalline and granular tetryl are listed. Results are given in mm for $m_{50\%}$, the gap width giving a 50% probability of shock to detonation, 95% probability limits, and standard deviation. The range of %TMD is as wide as 80-96% in some cases, but typically covers more restricted limits. The lower limit of %TMD (80%) is dictated by the necessity for the pellets to have sufficient mechanical strength for handling; the MRL SSGT uses unconfined acceptor pellets. Data from these tables are plotted in Figs 2-4.

Although our shock sensitivity data should preferably have been quoted in incident shock pressures rather than gap thicknesses, this was not possible because the MRL SSGT has not been calibrated for pressure output. However the similar AWRE SSGT [6] has been calibrated and, for the gap thicknesses used in this study, the pressure-gap relationship was found to be linear [11]; this has also been shown for the NOL SSGT over a considerable pressure range [9].

3. DISCUSSION

3.1 General Comments on Density/Shock Sensitivity Dependence

Current models of shock to detonation transition separate the physical processes into two distinct stages: ignition/initiation and buildup [20-23]. The relative importance of these two processes can be experimentally shown to depend principally on both the duration and pressure of the incident shock.

Gap testing characteristically uses relatively low pressure sustained shocks; most of the testing occurs around the marginal (50%) condition. Under these conditions a relatively small amount of explosive is ignited by the incident shock [23] and, because the diameter of the acceptor is usually several times the critical diameter, conditions are very favourable to buildup once reaction has commenced. Gap testing using tests such as the NOL SSGT has therefore been regarded as principally a test of ignition/initiation under shock. Decrease in density (%TMD) increases porosity hence the number and volume of inhomogeneities, and thus increases the probability of ignition. As a consequence shock sensitivity as measured by the NOL SSGT and related methods is typically observed to increase with decreasing %TMD.

In contrast, the short duration/relatively high pressure shocks delivered by flyer plates result in a large portion of the impacted explosive, perhaps as high as 50% [23], being ignited by the incident shock. The key process for success/failure to grow to detonation is buildup which must be achieved in the very short time before rarefactions quench the reaction. Higher %TMD favours buildup (shorter run distance) and critical energies for shock-to-detonation under short duration shock typically decrease with increasing %TMD [20, 21].

However one might envisage a more general picture for gap testing as depicted in Fig. 5 which follows from discussions in both the previous paragraphs. Thus for a given stimulus, as %TMD decreases, a situation should be reached whereby buildup becomes the crucial factor (rather than ignition) due to increased difficulty of propagation between grains. The point of optimum shock sensitivity, ie the maximum in Fig. 5, may be outside the range of densities at which most military explosives can be loaded. The only explosive for which data like that shown in Fig. 5 has been reported is nitroguanidine (NQ), where the maximum occurred at a density of 0.45 Mg/m^3 [24]. This of course is below even the bulk density of most military explosives. NQ can exhibit unusual shock sensitivity behaviour due to changes in critical diameter [25] and this result may not be general.

3.2 Possible Causes of the Trends Observed in the MRL SSGT

A number of possible causes for the apparent decrease in shock sensitivity with decrease in density observed using the MRL SSGT could be envisaged, and these either relate to properties of the materials and/or particular features of the test arrangement. They are discussed below.

3.2.1 Reduction in Particle Size at Increasing %TMD

Reduction in particle size at higher pressing loads (increased %TMD) has been proposed by Price [12] as the major reason for the difference in shock sensitivity/density behaviour between coarse and fine tetryl [13], as well as a number of other examples.

However the effect of particle size on shock sensitivity is not entirely unambiguous. Perhaps the best summary is a statement by Kennedy and Stresau [26]; "fine-particle powders are often harder to ignite than coarse powders, but reactions in fine powders grow to detonation more rapidly once ignited". While thresholds for reaction are usually lower for coarser materials subjected to the sustained shocks used in gap testing, the more usually determined 50% initiation pressure is often lower for smaller grain materials, ie higher shock sensitivity [1]. We have recently observed increased shock sensitivity (MRL SSGT, measured by increased 50% gap values) with decreasing particle size for a series of RDX Grade A sieve cuts pressed to 90 %TMD [27].

One of us [17] previously determined RDX particle size for RDX Grade A/AC629 91.9:8.1 pressed to density 1.57 Mg/m^3 (94 %TMD). The AC629 was extracted with carbon tetrachloride and the particle size of the pressed RDX showed a reduction, relative to the RDX from which the moulding powder was made, in weight average (227 down to 200 μm), number average (89 to 50 μm) and median (236 to 227 μm) particle size. Extraction of the unpressed moulding powder as a control gave results identical, within experimental error, with the starting RDX. We extracted pressed pellets of 97.94:2.06 RDX Grade A/AC629 with toluene saturated with RDX and determined particle size distribution (see Experimental). The results for pellets pressed to 80.8, 85.8, 91.0 and 96.1 %TMD are shown diagramatically in Fig. 6. We have made no attempt to quantify this data since each is derived from only a single pellet, but the clear trend is for an increased weight and number of fine particles (< 40 μm) with increased %TMD, indicating the expected increase in grain fracture at higher pressing loads.

A decrease in particle size at increased density is proven, and might explain the increase in shock sensitivity with increasing %TMD; the decrease in particle size by grain fracture during pressing may more than compensate for any decrease in shock sensitivity due to decreased porosity. CH-6, which will also experience increased grain fracture of the RDX at increased %TMD, exhibits a "normal" shock sensitivity/%TMD relationship using the NOL SSGT [9], ie increased shock sensitivity with decreasing %TMD. Quite some time after the RDX/AC629 measurements were performed we obtained a US production sample of CH-6 for another study and obtained the results shown in Table 2, which indicate decreased shock sensitivity from the MRL SSGT with decreasing %TMD. This indicates that the cause of the anomalous results obtained with the MRL SSGT lies not with the explosive samples but with the test.

3.2.2 Disruption of Surface Coating

An effect parallel to particle size reduction is disruption of surface coating for the RDX formulations. Crystal fracture exposes new (uncoated) RDX surface but a more significant factor could be debonding of the polymer coating by intercrystalline friction during compaction. Eadie [28] demonstrated as early as 1965 that shock sensitivity was strongly dependent upon coating efficiency for pressed HMX moulding

powders: at identical wax levels, the higher the surface coverage (least exposed HMX surface), the lower the shock sensitivity.

The proposal was therefore that pressing to higher %TMD resulted in increased debonding of the AC629 or polyurethane from the RDX crystals. The increased area of exposed RDX surface resulted in an increased shock sensitivity which more than compensated for the decrease due to decrease in porosity. Although a good idea in principle, it suffered from a major problem; how would one quantify this effect? Breakup of pellets to examine the interior crystals would itself result in surface disruption, while examination by scanning electron microscopy or FT IR of the pellet exteriors would not necessarily yield reliable information about the pellet interior.

However, as mentioned in the previous section, the differing behaviour of CH-6 in the MRL and NOL SSGTs indicates that the phenomenon is associated not with the material but with the tests.

3.2.3 Critical Diameter Effects

At this stage it was obvious that the trends observed were not a particular feature of the materials under test, but resulted from the test itself. Before commencing an analysis of possible causes, let us first look at the diagram of the most widely used test, the NOL SSGT (Fig. 7). The key difference between the NOL and MRL SSGT is in the acceptor; the NOL geometry is 5.095 mm diameter x 38.10 mm length confined in 25.40 mm o.d. brass, while the MRL geometry is 12.7 mm diameter x 25.4 mm length unconfined. Both tests used a donor* of similar diameter, with the NOL donor being longer and more confined, while the gap materials are different (compare Figs 1 and 7).

One suggestion** for explaining our unusual results was that the shock from the donor in the MRL SSGT was curved, and success/failure would depend critically on the width of the "flat" part of the shock front. Because we use an unconfined donor, this "flat" width may be so small as to be close to the critical diameter of the acceptor explosive. As the %TMD decreased, the critical diameter would increase [25] and consequently a stronger incident shock would be necessary to overcome the problem of the flat shock width being below the critical diameter. This would oppose the decrease resulting from greater porosity at lower %TMD. Although the NOL SSGT donor is smaller again, the acceptor is confined and this substantially decreases critical diameter.

Hutchinson [29] has shown by ultra high speed photography that the shock output of a UK Mk 3 EBW donor is planar to within 15 ns over the central 3 mm.

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* In our tests, we used a MRL Scale 1 donor in the earlier results (pre 1985) then changed to a UK Mk 3 donor; the latter differs from the MRL Scale 1 (Fig. 1) only in the geometry of the moulded plastic head and pins; the perspex barrel and explosive components are identical.

** We thank Mr Max Stosz of NSWC for this idea.

Although transmission through the brass gap may result in additional curvature, RDX/binder formulations with 15% or less binder typically have critical diameters of 1-2 mm [25] and should thus be well below the flat width of the incident shock.

Investigation as to whether donor shock width was the cause of the MRL trends was carried out by testing an RDX/AC629 95.0:5.0 formulation pressed at nominally 90 and 85 %TMD using the MRL Scale 2 gap test. This differs from the Scale 1 test which we normally use in having an additional 10.2 mm diameter high density PETN pellet between the EBW donor and brass shim (Fig. 1), resulting in a broader output pulse. The 95.0:5.0 formulation was chosen because it should have a critical diameter intermediate between the extremes of the compositions studied (Tables 1 and 2); stable detonation of 2 mm unconfined pellets at 90 %TMD was observed by us using streak photography in another unrelated study, thus critical diameter will be below 2 mm.

Results are detailed in Table 3 for the Scale 2 MRL SSGT at 89.3 and 85.5 %TMD, and for Scale 1 at 90.0% for comparison.

The gap thicknesses needed to attenuate the donor shock to the 50% probability limit are, as expected, substantially larger for Scale 2 than Scale 1. However the trend is the same as the Scale 1 results (Table 1). It can therefore be concluded that donor shock width/critical diameter cannot be the cause of our results. This will be discussed further in a summary of overall trends in the MRL gap test in a later section.

3.2.4 Run Distance Effects

A related factor which could produce differences because of the different geometry of the NOL and MRL SSGT acceptor is run distance. When a shock wave from an explosive donor is incident upon an explosive acceptor, reaction commences in the acceptor and this may or may not build to detonation. Transition to detonation does not normally occur instantaneously but is preceded by deflagration. The distance between the front face of the acceptor and the point at which detonation occurs is the run distance. A plot of log (incident pressure) vs log (run distance) is usually linear and known as a Pop plot [3]. Because the NOL SSGT has a longer acceptor (38.1 mm) than the MRL SSGT (25.4 mm), some tests at large gap/low incident pressure may not have built to detonation at the end of the acceptor in the MRL SSGT but could have in the NOL SSGT. Since run distance usually increases with decreasing %TMD, the sensitivity of lower %TMD samples may be underestimated by the MRL SSGT.

A large number of Pop plots are listed in Ref [3]. In particular there is extensive data for tetryl over the range 75.1-98.2 %TMD, and more limited data for the RDX formulations PBX 9407 (RDX/Exon 461 94:6) and PBX 9405 (RDX/NC/CEP 93.7:3.15:3.15). Taking the incident pressures at and below the 50% probability limit from NOL SSGT data [2, 9], run distances of at most 15 mm and typically below 10 mm would be expected for the booster formulations studied here. This is well short of the 25.4 mm length of the acceptor and strongly supports the conclusion that run distance is not a significant factor.

3.3 MRL SSGT : Summary of Data and Conclusions for Future Assessments

Gap tests are convenient and straightforward methods of assessing shock sensitivity. Their limitations have always been recognised; each test assesses the susceptibility of an explosive to be initiated to detonation in the particular geometry of the test by the particular donor used in the test. In general, qualitative rankings of explosive sensitivity will differ little from test to test, although quantitative relationships may vary appreciably.

A better understanding of the results obtained using the MRL SSGT could potentially be obtained by direct comparison with results for the same materials from another SSGT. We recently carried out a comparative assessment of booster explosives qualified as replacements for tetryl in the US using production samples supplied by NSWC through the auspices of TTCP WTP-1 [30], and for which corresponding shock sensitivity data from the NOL SSGT are readily available [2, 9, 31]. MRL SSGT and NOL SSGT data for these booster explosives, together with earlier data for TNT [11], are detailed in Table 4. Most of the data is for charges pressed to about 90 %TMD, with some additional data for CH-6 and tetryl at a second (lower) density. The 50% probability of detonation is given in terms of gap thickness (mm of brass shim) for the MRL test and shock pressure (GPa) in the NOL test. It is to be noted that these parameters vary in the opposite sense, with higher shock sensitivity represented by a larger gap or a smaller shock pressure.

Examination of data from Table 4 reveals the order of shock sensitivity, decreasing from left to right, for explosives pressed to 90 %TMD.

MRL SSGT:

Tetryl granular > HNS IIB ~ Tetryl crystalline > A-5 ~ CH-6 >
HNS IB ~ PBXN-5 > PBXW-7 > TNT > A-3

NOL SSGT:

A-5 > CH-6 > Tetryl > HNS IIB > PBXN-5 > TNT > PBXW-7 > A-3 > HNS IB

Two relevant observations may be made:

(i) Both tests rank the explosive/binder (wax) formulations in the same order, ie A-5 > CH-6 > PBXN-5 > PBXW-7 > A-3. Each material is granular and consolidates to charges with good mechanical strength. The relative shock sensitivities do vary somewhat. Noteworthy is PBXW-7 which is rated very much less sensitive than PBXN-5 in the MRL test but only a little less sensitive in the NOL test.

(ii) Pure crystalline explosives tend to be ranked as more sensitive by the MRL test (or alternatively the explosive/binder formulations are ranked as less sensitive). The pure materials examined in this study were of small particle size.

Perhaps the key result is for HNS IB which is the least sensitive explosive in the NOL SSGT but which is rated as quite sensitive by the MRL SSGT. HNS IB is a very fine particle size material (< 10 μm) [32] and as such should be difficult to ignite under the sustained shock conditions of a gap test, but will buildup to detonation very rapidly once suitably ignited [26]. It could equally be argued that the pure crystalline explosives cited in (ii) above will more readily undergo buildup than the waxed/desensitized formulations; it is widely held that the principal effect of waxes/binders is to hinder propagation/buildup, rather than ignition/initiation.*

The results from the MRL SSGT appear then to be significantly influenced by buildup to detonation as well as ignition, although as discussed in Section 3.1, gap testing has been regarded principally as an assessment of ease of ignition. The heavy confinement of the acceptor charge in th. NOL SSGT and related tests minimizes energy losses from side rarefactions. In the unconfined acceptor of the MRL SSGT these energy losses are more significant and buildup to detonation becomes a more important factor.

It is therefore proposed that the principal reason that the MRL SSGT data shows an apparent reduction in shock sensitivity with reduction in %TMD over the range 96-80 %TMD** is the decreased ability to undergo buildup in the lower %TMD charges. In this respect the MRL data therefore parallels flyer plate shock sensitivity [20, 21] in many respects.

The only gap test for which comparative shock sensitivity has been determined on both confined and unconfined acceptors is the NOL Large Scale Gap Test (LSGT) [10] and the Low Amplitude Shock Initiation Test (LASI) [33] which is derived from the NOL LSGT. The limited NOL LSGT results which are available indicate that there is an approximately linear correlation between shock sensitivity from the standard (confined) test and the same test where the confinement has been removed; higher shock pressure/lower gap thickness is required for 50% detonation probability in the unconfined test [10, 12]. Results from the LASI test, which uses an unconfined acceptor, afford the same general picture when compared with analogous NOL LSGT results [33]. The threshold for burning was also affected by confinement in some cases [33]. Unfortunately no experimental results on unconfined charges over a range of densities have been published, but the general results support our conclusions outlined in the previous paragraph.

What does this mean for use and interpretation of data from the MRL SSGT? Clearly the sensitivity ranking of related formulations such as the wax/binder materials described earlier in this section are correctly predicted. Similarly the shock sensitivity of waxed formulations decreases with increasing wax content (see Fig. 2) as expected; this should be the trend for decreased ability to undergo buildup and thus should be

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* However it must be cautioned that we are dealing with different explosives with different intrinsic kinetic and thermodynamic properties.

** No attempt has been made to study lower %TMD pressed charges since the mechanical strength of the unconfined donors is usually inadequate below about 80 %TMD. Higher %TMD are also not of particular interest because production Australian pressed fillings are typically less than 95 %TMD.

expected to be correctly predicted. Overall, the data broadly follows the "expected" order of sensitivity [11].

A number of problem areas stand out:

(i) Materials dissimilar in particle size and/or physical form such as waxed versus unwaxed; the MRL SSGT could rate the material that can undergo buildup more readily as the more sensitive.

(ii) Results from different materials at different %TMD should never be compared directly.

(iii) The $m_{50\%}$ result for relatively insensitive materials will overestimate the insensitivity of these materials. For example, $m_{50\%}$ for A-3 (0.498 mm) can be compared with A-5 or CH-6 (approx. 2.6 mm) while the NOL results are > 2 GPa and 1.03 and 1.21 GPa respectively (Table 4). A-5 is not five times more sensitive than A-3 as might be imagined from crude comparison of the MRL SSGT results. The problem here is that at very small gap widths (A-3) the linear relationship between gap width and pressure breaks down [9], and is compounded by the larger critical diameter (see section 3.2.3) and poorer buildup in these insensitive materials. For example the apparently decreased sensitivity of PBXW-7 in the MRL SSGT relative to the NOL SSGT probably results from a combination of these latter effects.

4. CONCLUSIONS

The consistent observation that the shock sensitivity of pressed explosives as determined by the MRL SSGT decreases with decreasing %TMD has been investigated. Reduction of particle size upon compaction, disruption of surface coating in wax/binder formulations, and run distance effects were shown not to be major factors. Critical diameter effects were similarly shown not to be important except for relatively insensitive compositions. It is proposed that the principal cause derives from the use of an unconfined acceptor which results in buildup becoming an important factor. The NOL SSGT, which uses a heavily confined acceptor, is principally a test of ignitability. Consequently the MRL SSGT will rate shock sensitivity of materials which do not readily undergo buildup as lower than will the NOL SSGT. Decrease in %TMD decreases the ability to undergo buildup. Some experiments to assess the effect of confinement are planned for the future.

Continued use of the MRL SSGT to assess shock sensitivity must necessarily involve caution in direct comparison between materials. In particular, no conclusions should be drawn from results from different materials at different %TMD, and materials with dissimilar particle size and/or physical form should be compared with caution. The sensitivity of sensitive materials such as boosters will be overrated relative to pressed main charge fillings. Nonetheless the MRL SSGT has been an excellent vehicle for comparison in the past, and will continue to be if results are used with discretion.

5. EXPERIMENTAL

5.1 Materials

The preparation and characterisation of the RDX Grade A Class 1 (recrystallised ex Albion Explosives Factory) and RDX Grade B Class 1 (milled and boiled ex Albion)/AC629 Emulsifiable Polyethylene Wax (Allied Chemicals) have been described in detail previously [16-18]. The RDX/Impranil DLH (Bayer) Emulsifiable Polyurethane/Zinc Stearate formulations have also been described in detail [19]. Crystalline and granular tetryl were obtained from MFF St Marys and CH-6 (NSWC X-963 Lot # HOL 78C-900-032, Batch # 4R-18-7) was obtained from NSWC Whiteoak.

5.2 Shock Sensitivity

The MRL SSGT has been briefly described in the Introduction and full details can be found in ref. [11]. The donors used were either MRL scale 1 [11] or UK Mk 3 EBWs supplied by AWRE Aldermaston. The latter differ from the MRL scale 1 donor shown in Fig. 1 only in the shape of the moulded plastic head and pins: all other features are common. Duplicate determinations using both donors showed comparable results. Acceptor samples were pressed to the required density on an Instron Universal Testing Machine operated as a press. Complete experimental details are given in ref. [16]. Pellets were pressed at the required load for two successive 1 min periods. The SSGT was performed on 25-30 shots using standard Bruceton staircase procedure and analysis [8].

5.3 Particle Size Measurements

The pressed pellet (2.5 g) was heated for 30 min at 100^{o}C with toluene saturated with RDX at 100^{o}C (100 mL). Pellets pressed at 80-90 %TMD fell apart rapidly but the 95% TMD pellets needed to be gently broken up with a teflon spatula. After 30 min the RDX was filtered off while still hot, washed with RDX saturated toluene and dried under suction. Recovery of decoated RDX typically was about 96%.

Particle sizes were determined using a Malvern Particle Size Analyser Model 2600/3600. The powder was split into small fractions using a rotary sample divider and these fractions were slurried in water. Measurements were performed in triplicate. It was found that ultrasonic treatment resulted in considerable increases in "fine" particles, particularly for the samples taken from pressed pellets, and this increased with increasing length of treatment. As a consequence comparison of samples was made without ultrasonic treatment.

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TABLE 1

Shock Sensitivity (MRL SSGT) for RDX Grade A/AC629 Polyethylene Wax Formulations Pressed to Various %TMD

Composition RDX Grade A/AC629	Shock Sensitivity (mm)			
	Relative Density (%TMD)	$M_{50\%}$	Range $L_{95\%}$	Standard Deviation
98.69:1.31 [a]	95.9	2.651	2.692-2.611	0.019
	91.0	2.593	2.642-2.548	0.020
97.94:2.06 [a]	96.1	2.614	2.705-2.522	0.042
	91.0	2.431	2.507-2.352	0.036
	85.8	1.880	1.938-1.821	0.027
	80.8	1.656	1.725-1.588	0.032
97.14:2.86 [a]	96.1	2.474	2.586-2.365	0.052
	90.9	2.276	2.377-2.174	0.048
95.31:4.69 [a]	95.9	2.126	2.174-2.078	0.022
	90.8	1.681	1.737-1.628	0.026
94.61:5.39 [a]	95.7	1.831	1.877-1.786	0.022
	90.8	1.288	1.331-1.246	0.019
91.9:8.1 [b]	96.48	1.744		0.050
	96.18	1.711		0.017
	95.46	1.659		0.042
	94.50	1.676		0.019
	93.91	1.563		0.015
	92.77	1.253		0.022
	91.94	0.953		0.022

a Data from Ref. [18]

b Data from Ref. [17]

TABLE 2

Shock Sensitivity (MRL SSGT) for Some Selected RDX Formulations and Tetryl Pressed to Various %TMD

Composition RDX Grade A/AC629	Shock Sensitivity (mm)			
	Relative Density (%TMD)	$M_{50\%}$	Range $L_{95\%}$	Standard Deviation
RDX Grade B/AC629 [a] Polyethylene wax (92.3:7.7)	95.97	1.770		0.014
	95.74	1.836		0.022
	95.41	1.676		0.053
	95.14	1.593		0.052
	94.67	1.649		0.030
	93.72	1.684		0.022
	92.60	1.532		0.014
	91.23	1.201		0.049
	89.04	1.100		0.022
RDX Grade A/Impranil [b] DLH polyurethane/ zinc stearate 100.00:2.00:1.03	95.11	2.616	2.692-2.540	0.036
	90.04	2.268	2.314-2.223	0.021
	85.03	1.814	1.875-1.753	0.028
CH-6: RDX/polyisobutylene/calcium stearate/ graphite 97.5:0.5:1.5:0.5	90.0	2.600	2.654-2.548	0.025
	85.0	2.352	2.400-2.304	0.022
Tetryl crystalline	90.0	2.814	2.858-2.771	0.021
	80.0	2.637	2.667-2.609	0.014
Tetryl granular [c]	90.0	3.259	3.315-3.203	0.026
	83.5	2.814	2.934-2.692	0.056

a Data from Ref. [16]

b Data from Ref. [19]

c Data from Ref. [18]

TABLE 3

A Comparison of Data for RDX/AC629 (95.0:5.0) Determined Using the MRL SSGT at Scale 1 and Scale 2

MRL SSGT Type	Shock Sensitivity (mm)			
	Relative Density (%TMD)	$M_{50\%}$	Range $L_{95\%}$	Standard Deviation
SCALE 1	90.0	1.433	1.511-1.356	0.037
SCALE 2	89.3	4.018	4.155-3.881	0.063
	85.5	3.360	3.584-3.137	0.098

TABLE 4

Comparison of MRL SSGT and NOL SSGT Results for Selected Pressed Booster Explosives, TNT and Composition A-3

FORMULATION	MRL SSGT		NOL SSGT[a]	
	%TMD	$M_{50\%}$ (mm)	%TMD	$P_{50\%}$ (GPa)[b]
A-5 (RDX/stearic acid 98.75:1.25)	90.0	2.642	89.7	1.03
CH-6 (RDX/polyisobutylene/calcium stearate/graphite 97.5:0.5:1.5:0.5)	90.0	2.600	90.0	1.21
	85.0	2.352	84.9	1.02
PBXN-5 (HMX/Viton A 95:5)	90.0	2.383	90.5	1.98
PBXW-7 Type II (RDX/TATB/Viton A 35:60:5)	90.0	1.415	90.5[c]	2.16[c]
HNS Type IB	90.1	2.438	89.4	2.49
HNS Type IIB	90.0	2.822	88.8	1.55
Tetryl crystalline	90.0	2.814	89.5	1.31
	80.0	2.637	82.4	0.97
Granular	90.0	3.259		
	83.5	2.814		
TNT pressed	90.3	0.688	90.3	2.03
	92.1	1.219	93.6	2.22
A-3 (RDX/wax 91:9)	90.9	0.498	89.9	>2[d]

a Data from Refs [2, 9] unless stated otherwise.

b Converted from Dbg to GPa using the conversion relationship in Ref [2].

c Data for Type I ie PTFE instead of Viton A binder. These figures are from Ref [30] and are the average of 87.9 %TMD/1.95 GPa and 93.0/2.37.

d Data are only available from LSGT where $P_{50\%}$ is 1.5 GPa.

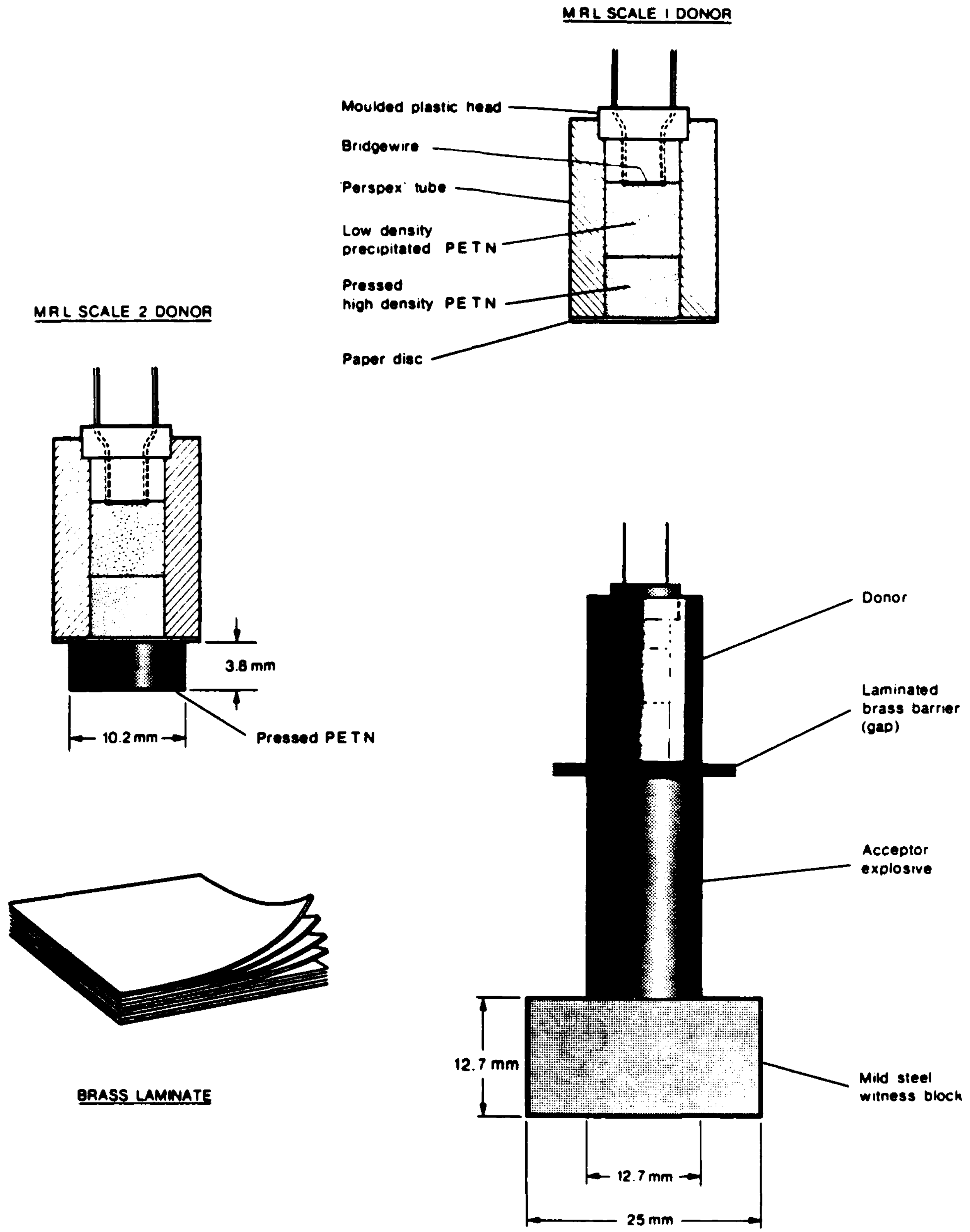

FIGURE 1 The MRL small scale gap test (SSGT) assembly.

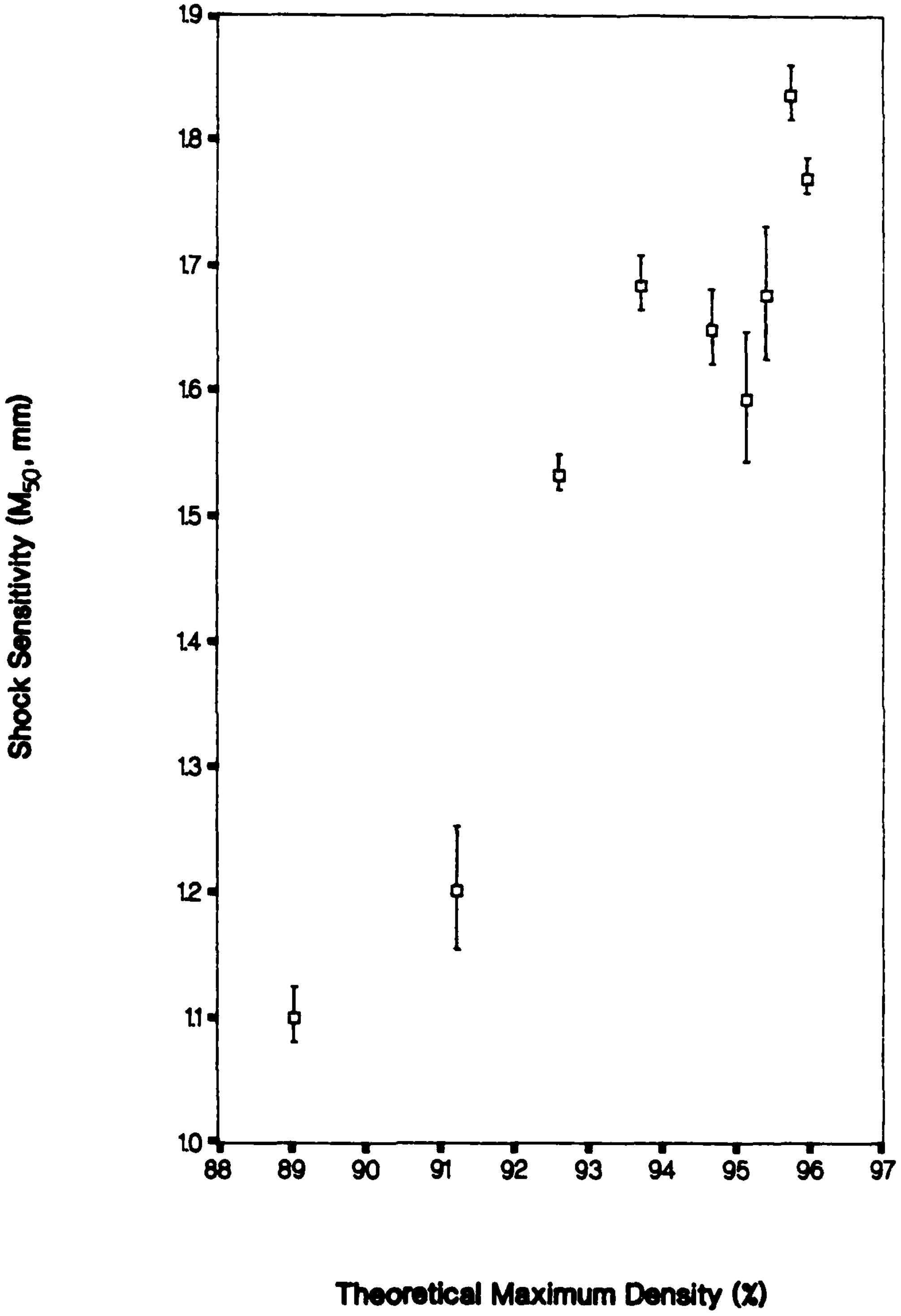

FIGURE 2 Shock sensitivity of RDX Grade B/Polyethylene Wax AC629 (92.3:7.7) as a function of density.

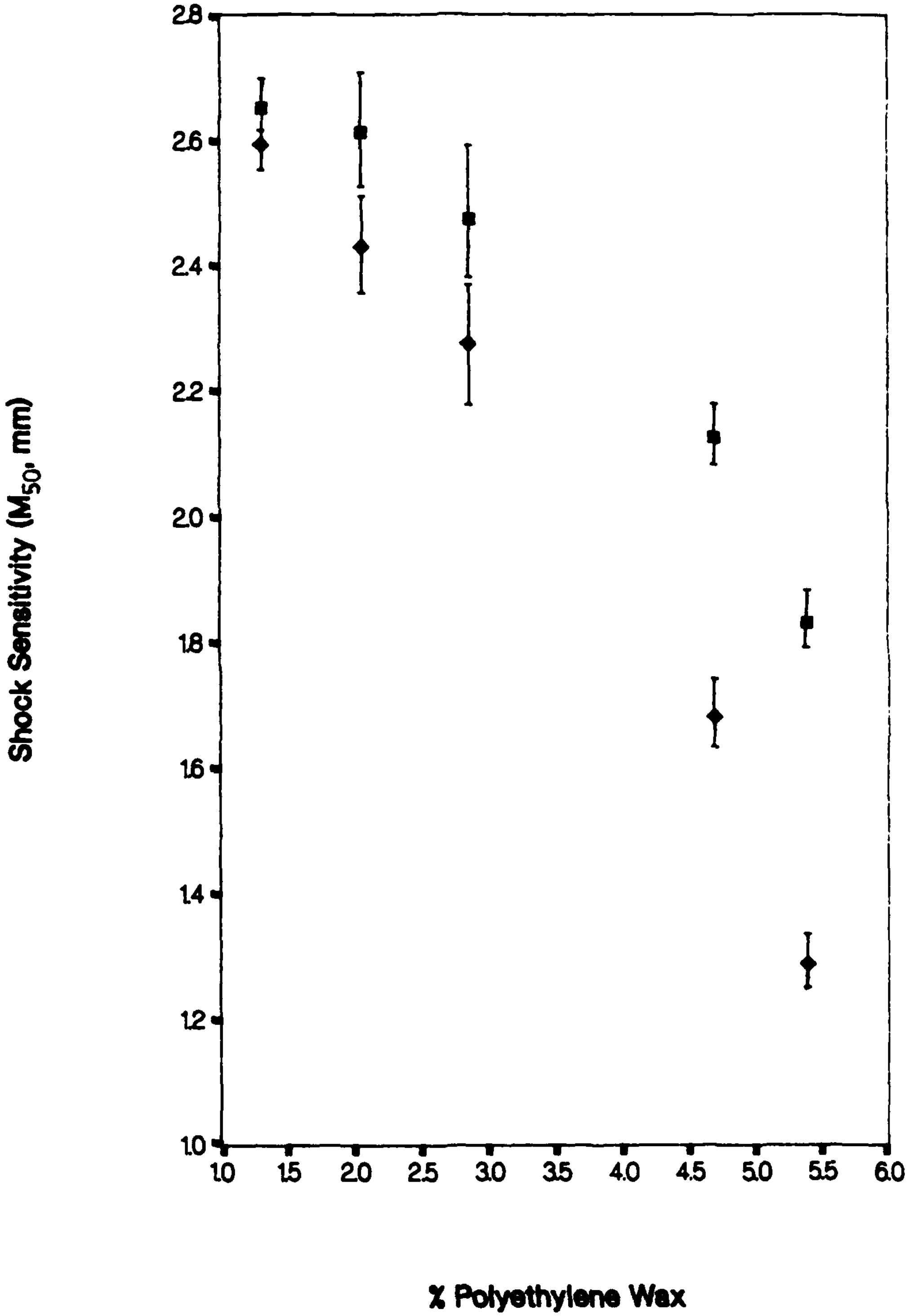

FIGURE 3 A plot of shock sensitivity ($M_{50\%}$), measured as mm of brass shim attenuator in the MRL SSGT, versus wax content (%) for RDX/AC629 polyethylene wax moulding powders.
■ 95 %TMD, ◆ 90 %TMD
Limit bars represent $L_{95\%}$ probabilities.

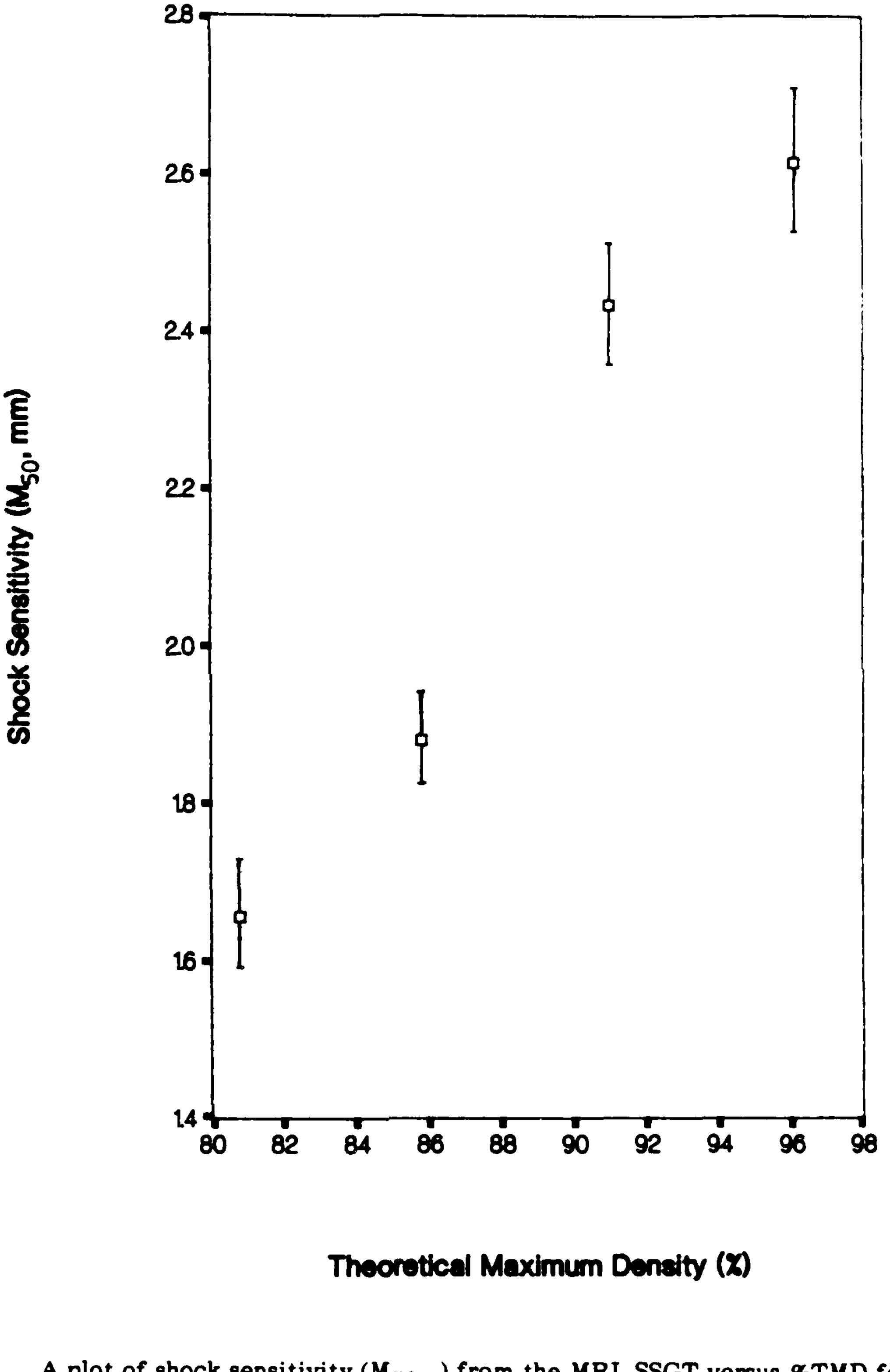

FIGURE 4 A plot of shock sensitivity ($M_{50\%}$) from the MRL SSGT versus %TMD for the RDX/AC629 97.94:2.06 moulding powder. Limit bars represent $L_{95\%}$ probabilities.

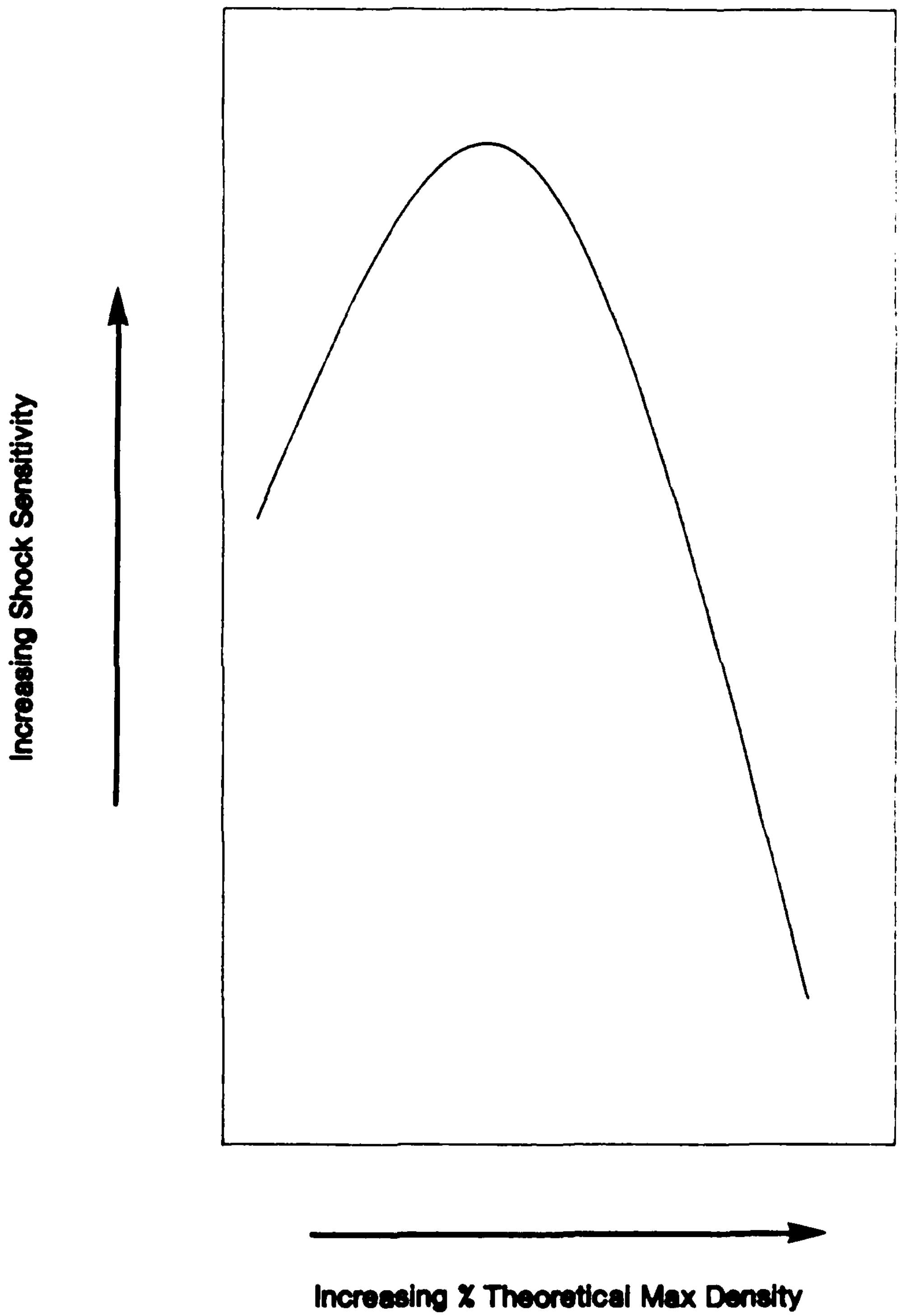

FIGURE 5 A "normal" shock sensitivity/%TMD relationship expected from gap testing.

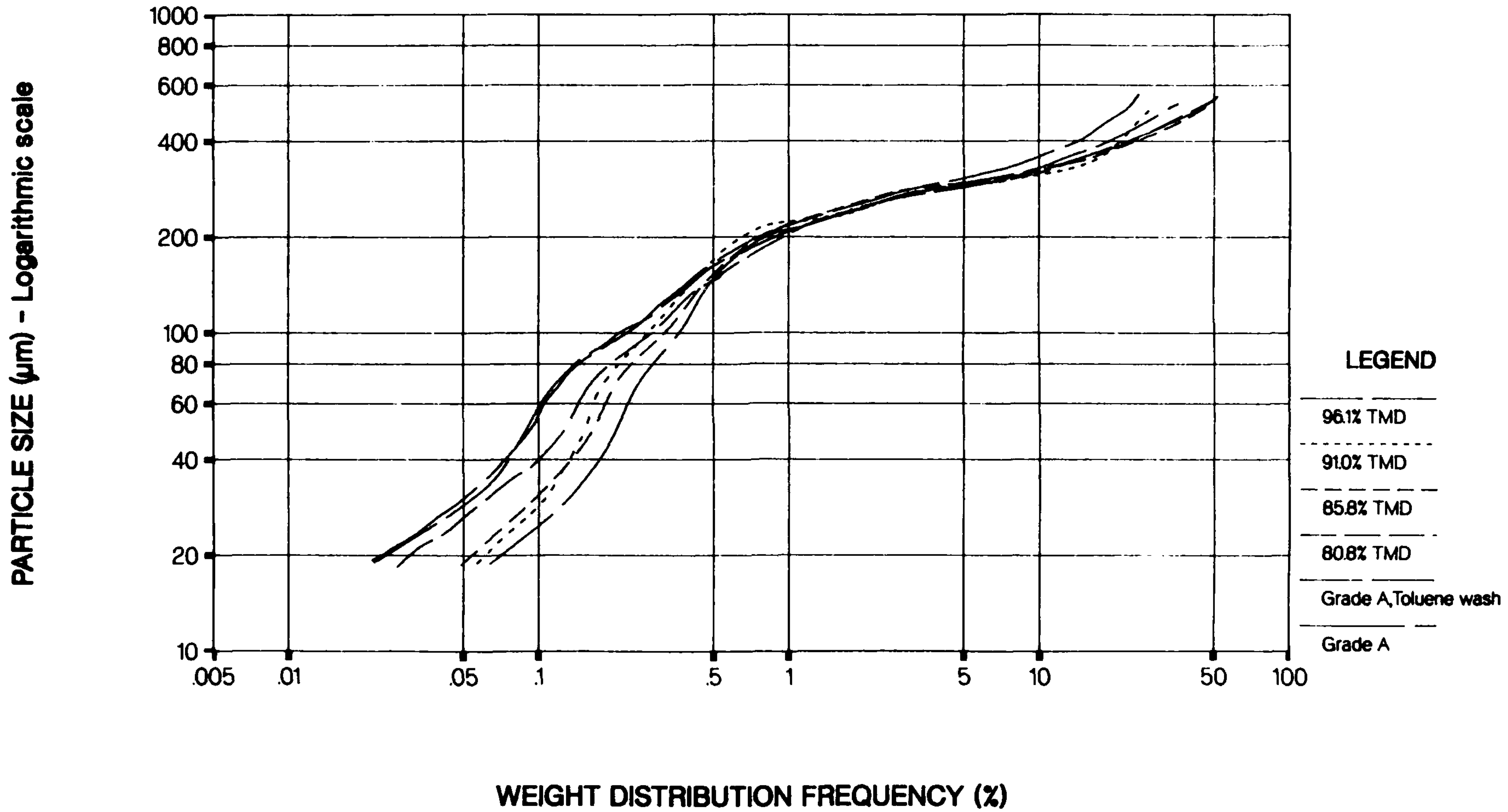

FIGURE 6 A plot of particle size distribution for RDX Grade A and RDX/AC629 97.94:2.06 pressed to a range of %TMD.

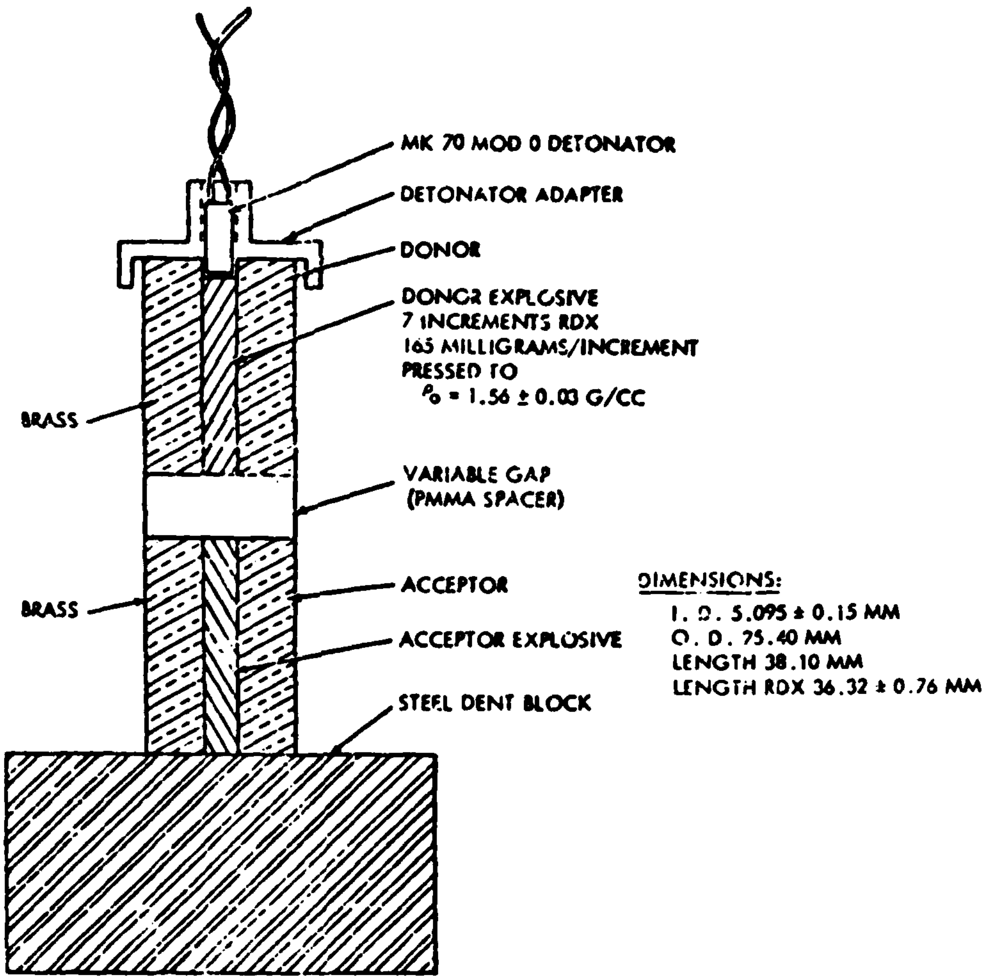

FIGURE 7 A diagram of the NOL SSGT Assembly.

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Anomalous shock sensitivity/density relationship for RDX-polyethylene wax and related formulations from MRL small scale gap test (SSGT) measurements

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ABSTRACT

Shock sensitivity as measured by the MRL SSGT shows a consistent trend to lower values as %TMD decreases for pressed RDX formulations and some pure explosives such as tetryl. Decrease in particle size, disruption of surface coating, critical diameter and run distance effects were all considered but found not to be the major cause. Comparison of MRL SSGT data for a series of production booster explosives with corresponding NOL SSGT data at 90 %TMD suggested that the ability to undergo buildup is significantly more important for the MRL SSGT. Reasons for this difference are discussed, and limitations for assessment of data using the MRL SSGT are outlined.

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